Objectives/outcomes: You will learn the following:

• Martensitic transformation via quenching
• Martensite: crystal structure and properties
• The isothermal decomposition of austenite. The TTT (time-temperature transformation) diagram. Formation pearlite and bainite.
• Decomposition of austenite on continuous cooling (CCT diagram). Formation of martensite and the martensite lines. The structure of martensite.
• Annealing, quench hardening, and austempering.
• Tempering of martensite. Heat treatment of noneutectoid plain carbon steel.
Heat treatment of plain carbon steels.

- What determines the property of the steel?
- **Heat treatment:** Heating and cooling changes mechanical properties.
- **Martensite:** Metastable phase consisting of super saturated solid solution of C in BCC or BCT tetragonal iron.
- Caused by rapid cooling of austenitic steel into room temperature (quenching).
  - \( M_s \): temperature of martensite start.
  - \( M_f \): temperature of martensite finish.

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Microstructure of Fe – C Martensites

- **Lath martensite**: Less than 0.6% C and consists of domains of lathe of different orientation.
- **Plate martensite**: More than 0.6% C and have fine structure of parallel twins.
TEM: Lathe martensite and plate martensite

Lathe martensite

Plate Martensite
Martensite (Cont..)

- **Transformation to martensite is** **diffusionless.**

- **BCC: position of carbon atoms**
- **BCT**
Strength of martensite

- Strength and hardness **increases** with carbon content.
- Strength is due to high **dislocation and twin concentration** and interstitial solid solution strengthening.

**Key Points on martensite:**
- Transformation with no diffusion
- High strength
- High hardness
- High internal stress
Isothermal decomposition of Austenite (TTT diagram): Pearlite.

- Several samples are first **austenitized** above eutectoid temperature and **rapidly cooled** to desired temperature and then **hold** for various time intervals.

**Key Points on Pearlite transformation:**

- **diffusion**
- **lower strength**
- **lower hardness**
- **lower internal stress**
Isothermal decomposition of Austenite (Cont..)

- If hot quenching temperature is between 550°C to 250°C, an intermediate structure Bainite is produced.
- Bainite contain nonlamellar eutectoid structure of α ferrite and cementite.
- **Upper Bainite** Between 550°C and 350°C
- **Lower Bainite** Between 350°C and 250°C

Key Points on Bainite transformation:
- Intermediate between martensite and pearlite
IT Diagrams for Noneutectoid Steels

- ‘S’ curves of IT diagrams of noneutectoid steel is shifted to left.
- Not possible to quench from austenitic region to produce entirely martensite (Why?).
- Additional transformation line indicates start and formation of proeutectoid ferrite.

**Key:** TTT (time-temperature-transformation) diagram is isothermal diagram
Continuous Cooling-Transformation (CCT) Diagram

- In continuous cooling transformation from martensite to pearlite takes place at a range of temperature.
Annealing and Normalizing

- **Full annealing**: Sample heated to $40^\circ C$ above austenite ferrite boundary, held for necessary time and cooled slowly.
- **Process annealing**: Used for stress relief. Applied to hypoeutectoid steel at eutectoid temperature.
- **Normalizing**: Steel heated in austenite region and cooled in still air.
- Makes grain structure uniform
Tempering of Plain Carbon Steel

- Martensitic steel is heated at a temperature below eutectic temperature.
- Makes steel **softer and ductile**.
- Carbon atoms, in low carbon steels, segregate themselves on tempering.

<table>
<thead>
<tr>
<th>Tempering Temperature</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 2000°C</td>
<td>Epsilon Carbide</td>
</tr>
<tr>
<td>200 – 700°C</td>
<td>Cementite (rod-like)</td>
</tr>
<tr>
<td>400 – 700°C</td>
<td>Cementite (Spheroidite)</td>
</tr>
</tbody>
</table>
Effects of Tempering

- Hardness decreases as temperature increases above 200°C.
- This is due to the formation of Fe$_3$C precipitates.

Key: Tempering is a critical step after quenching to form martensite: Relieve internal stress, increase the ductility, obtains the desired hardness/strength and ductility balance.
Classification of Plain Carbon Steel

- **Four digit** AISI-SAE code.
- First two digits, **10**, indicate **plain carbon steel**.
- Last two digits indicate **carbon content** in 100\(^{th}\) wt\%.
- **Example:** **1030** steel indicate plain carbon steel containing **0.30 wt\%** carbon.
- As carbon content increase, steel becomes stronger but less ductile.
HW

- Example problems: 9.4,
- Chapter 9: Download from website
- Reading assignment: 9.4, 9.5.1